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(54) REACTOR, MOTOR DRIVER, POWER CONDITIONER AND MACHINE

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(57) ABSTRACT

A reactor includes an outer peripheral iron core, and at least three core coils contacting or connected to an inner surface of the outer peripheral iron core. Each of the core coils includes a core and a coil wound onto the core. The reactor further includes cooling units disposed in end surfaces of the outer peripheral iron core, for cooling the outer peripheral iron core.

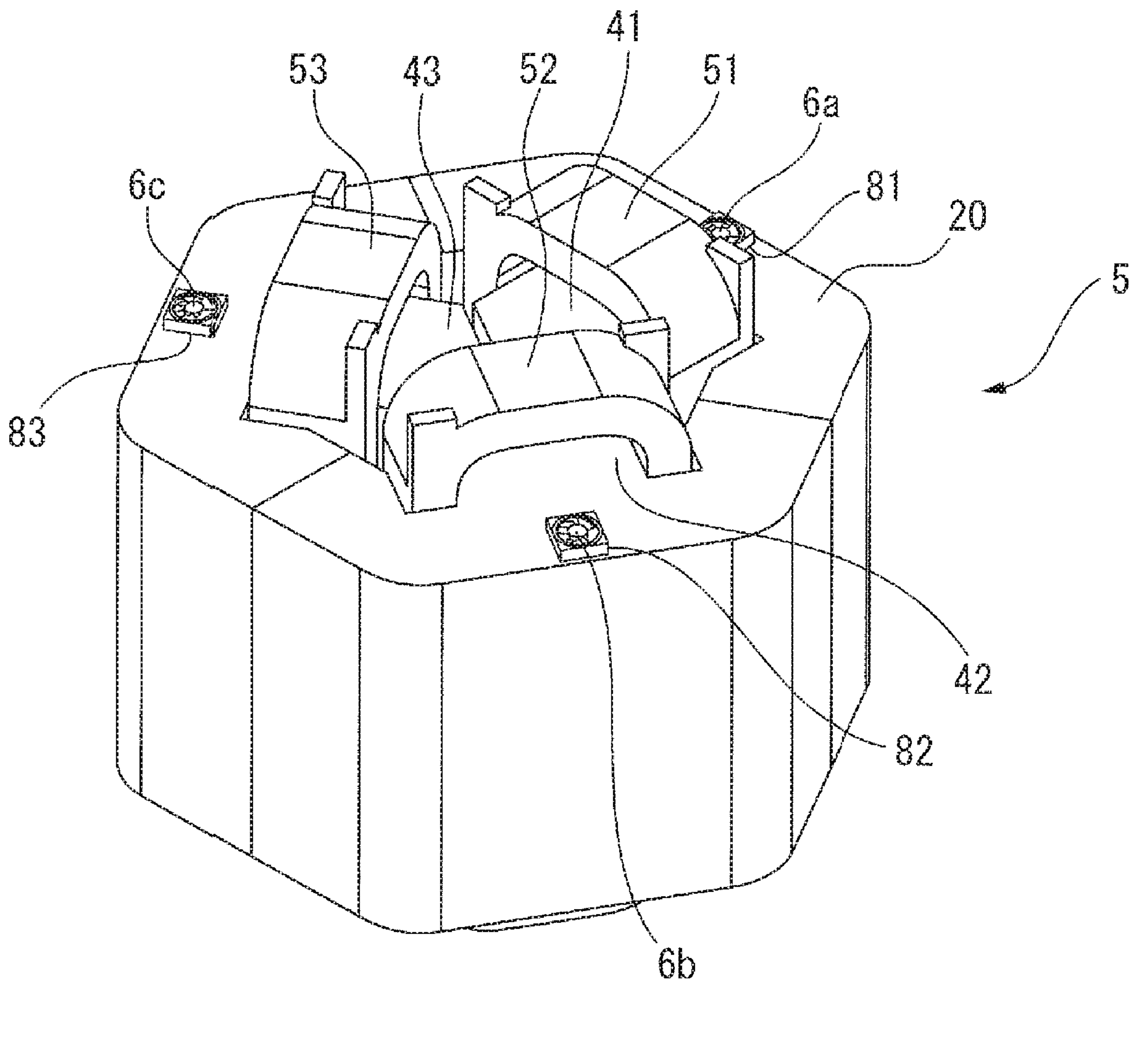


FIG. 1A

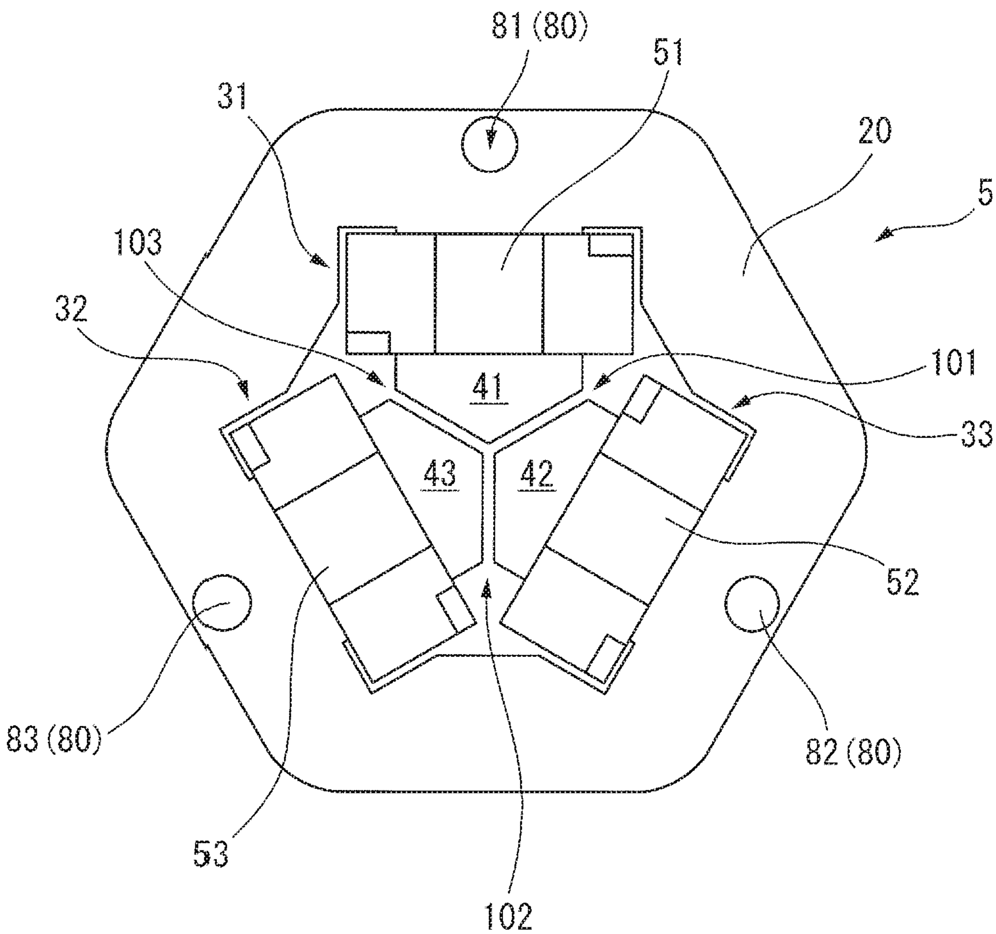


FIG 1B

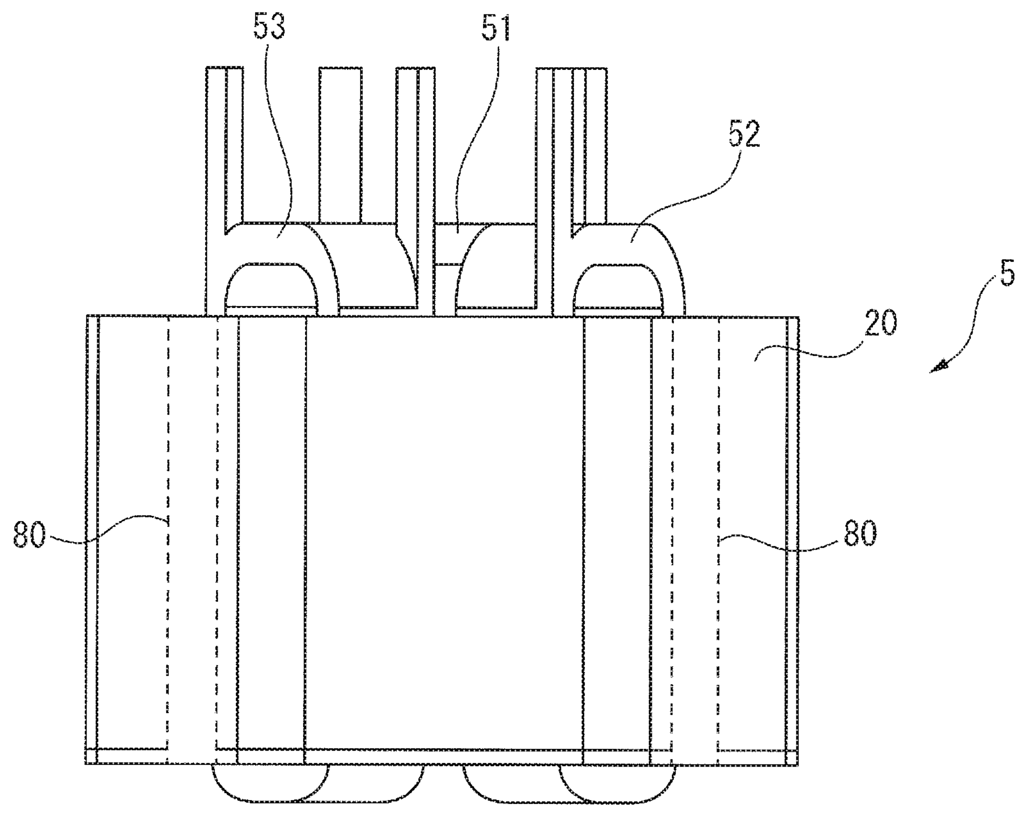
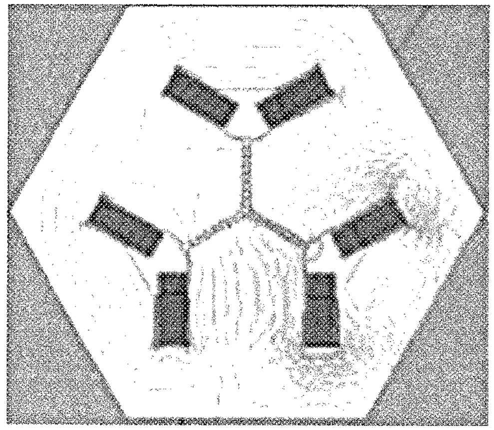
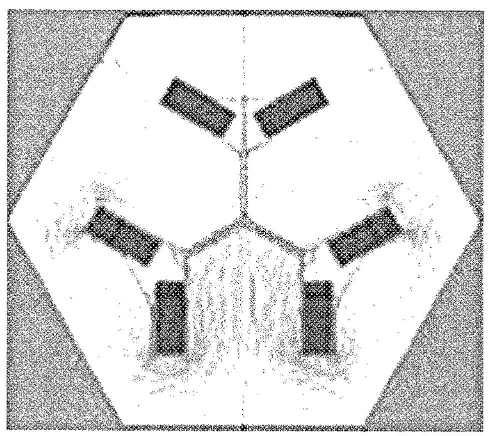


FIG. 2A



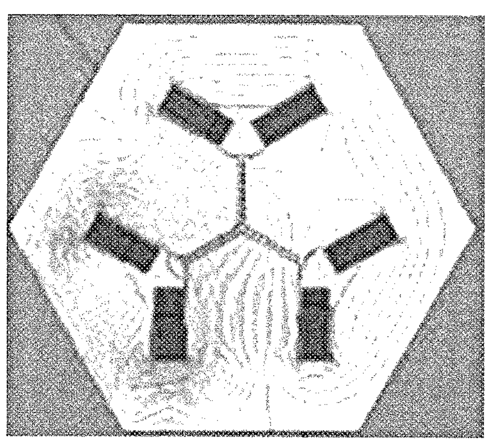
π/6

FIG. 2B



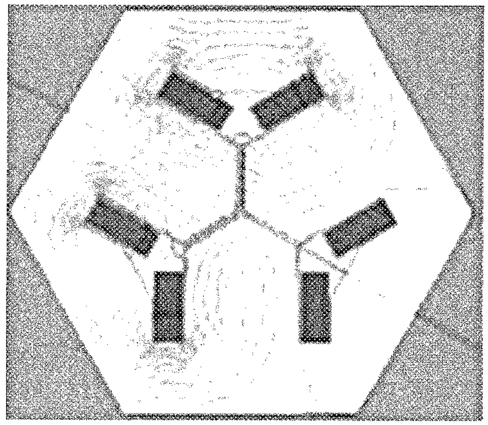
π/3

FIG. 2C



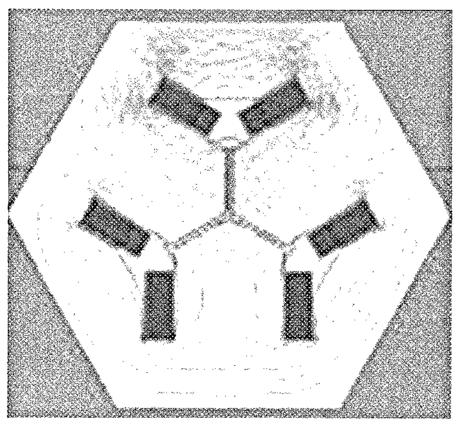
π/2

FIG. 2D



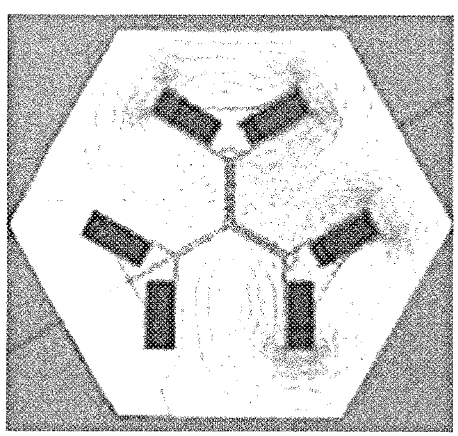
$2\pi/3$

FIG. 2E



$5\pi/6$

FIG. 2F



π

FIG. 3

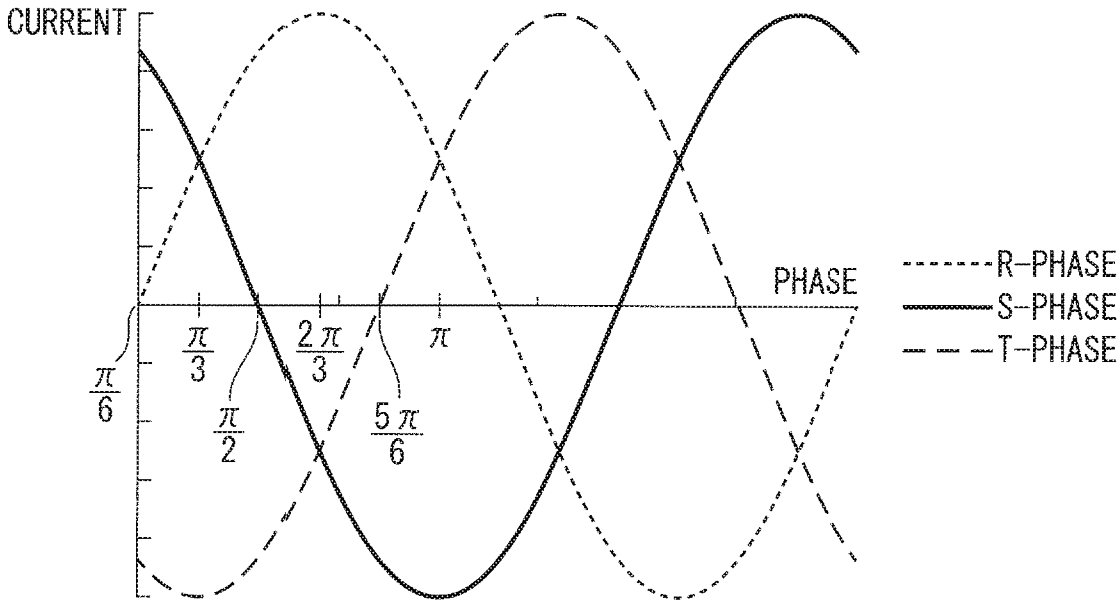

CURRENT
PHASE
π/6
π/3
π/2
2π/3
5π/6
π
R-PHASE
S-PHASE
T-PHASE

FIG. 4A

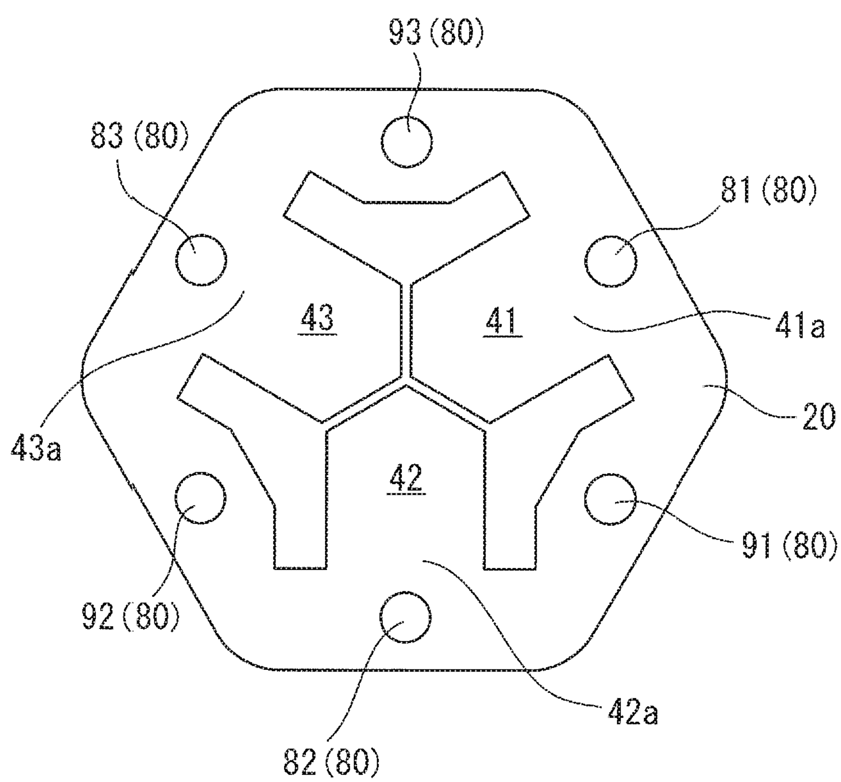

93 (80)
83 (80)
81 (80)
43
41
41a
20
43a
42
92 (80)
91 (80)
42a
82 (80)

FIG. 4B

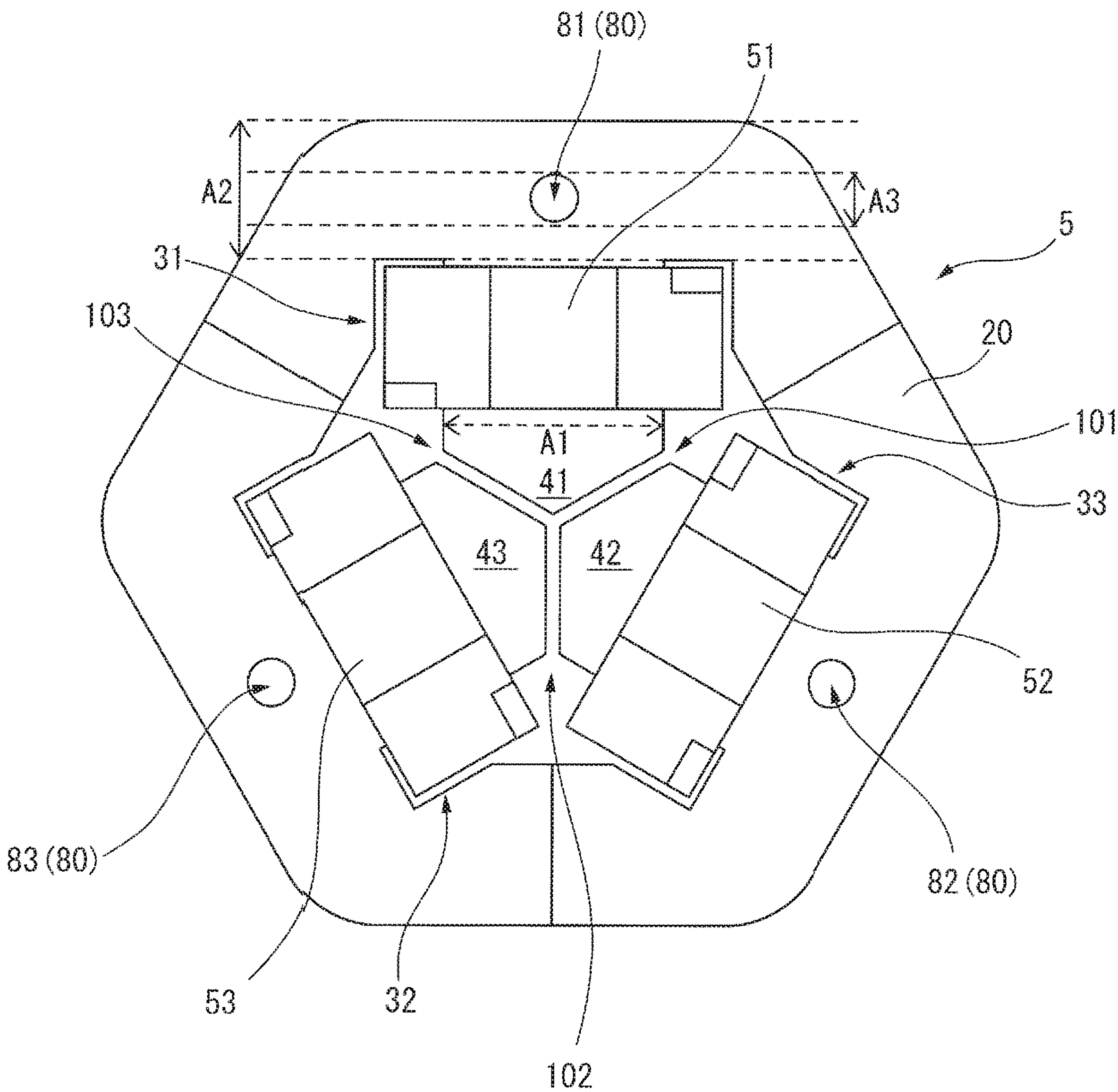


FIG. 5

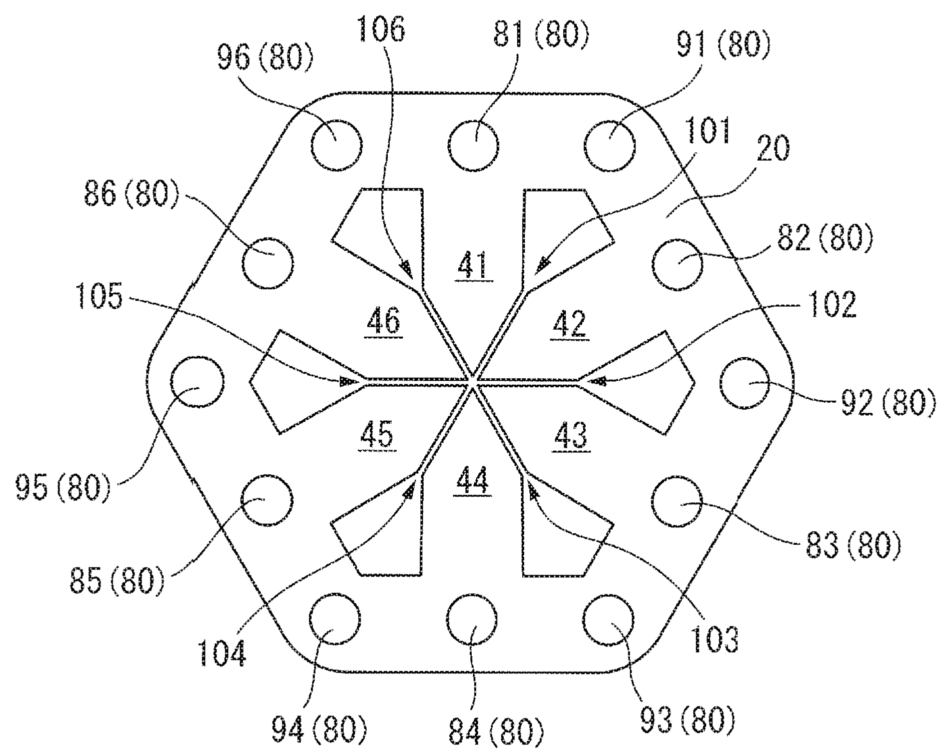

106
81 (80)
91 (80)
96 (80)
101
20
86 (80)
82 (80)
41
46
42
105
102
92 (80)
45
43
44
95 (80)
83 (80)
85 (80)
104
103
94 (80)
84 (80)
93 (80)

FIG. 6

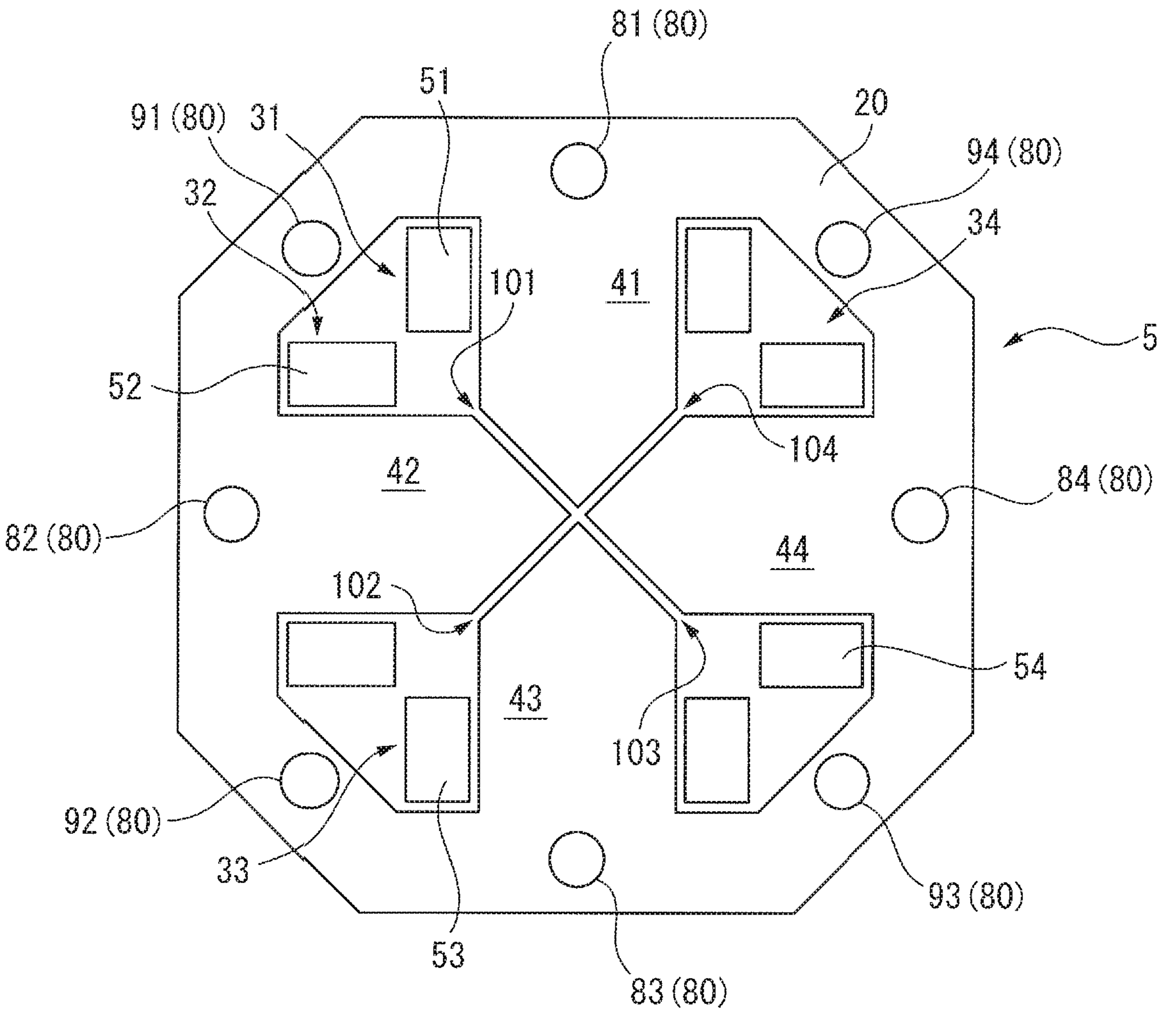

81 (80)
20
51
91 (80)
31
94 (80)
32
34
101
41
5
52
104
42
84 (80)
82 (80)
44
102
54
43
103
92 (80)
33
93 (80)
53
83 (80)

FIG. 7A

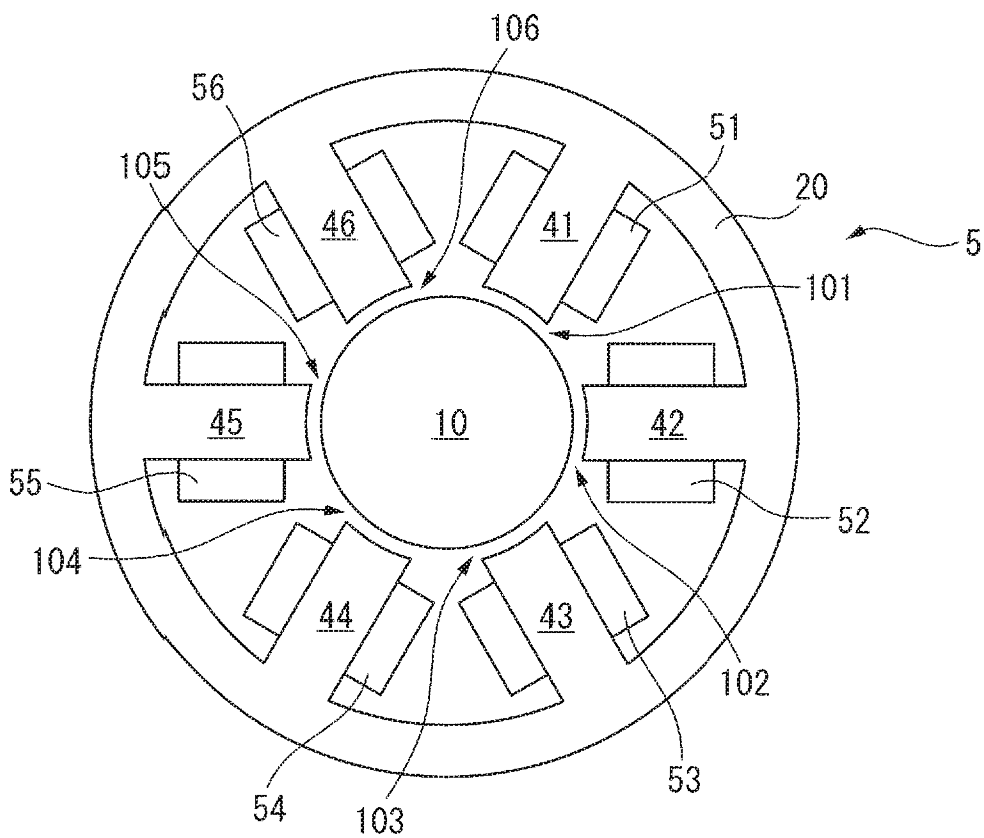


FIG. 7B

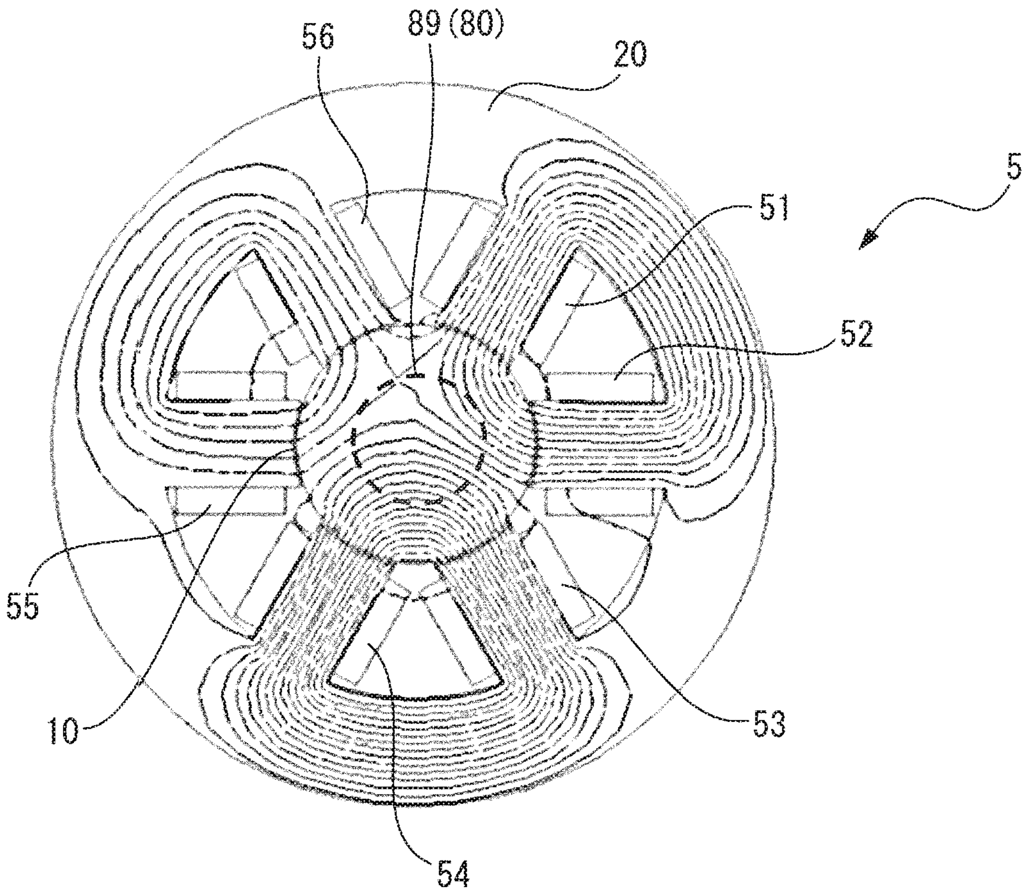


FIG. 8

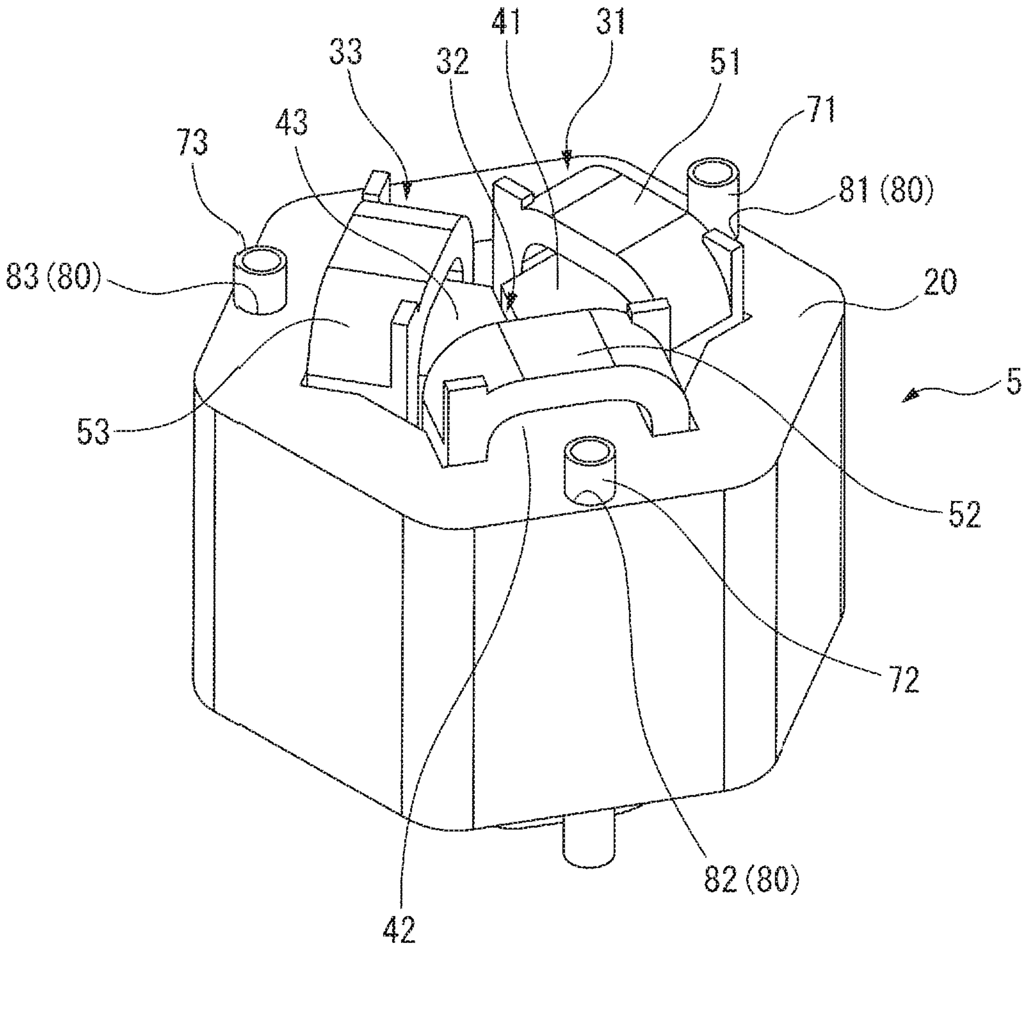


FIG. 9

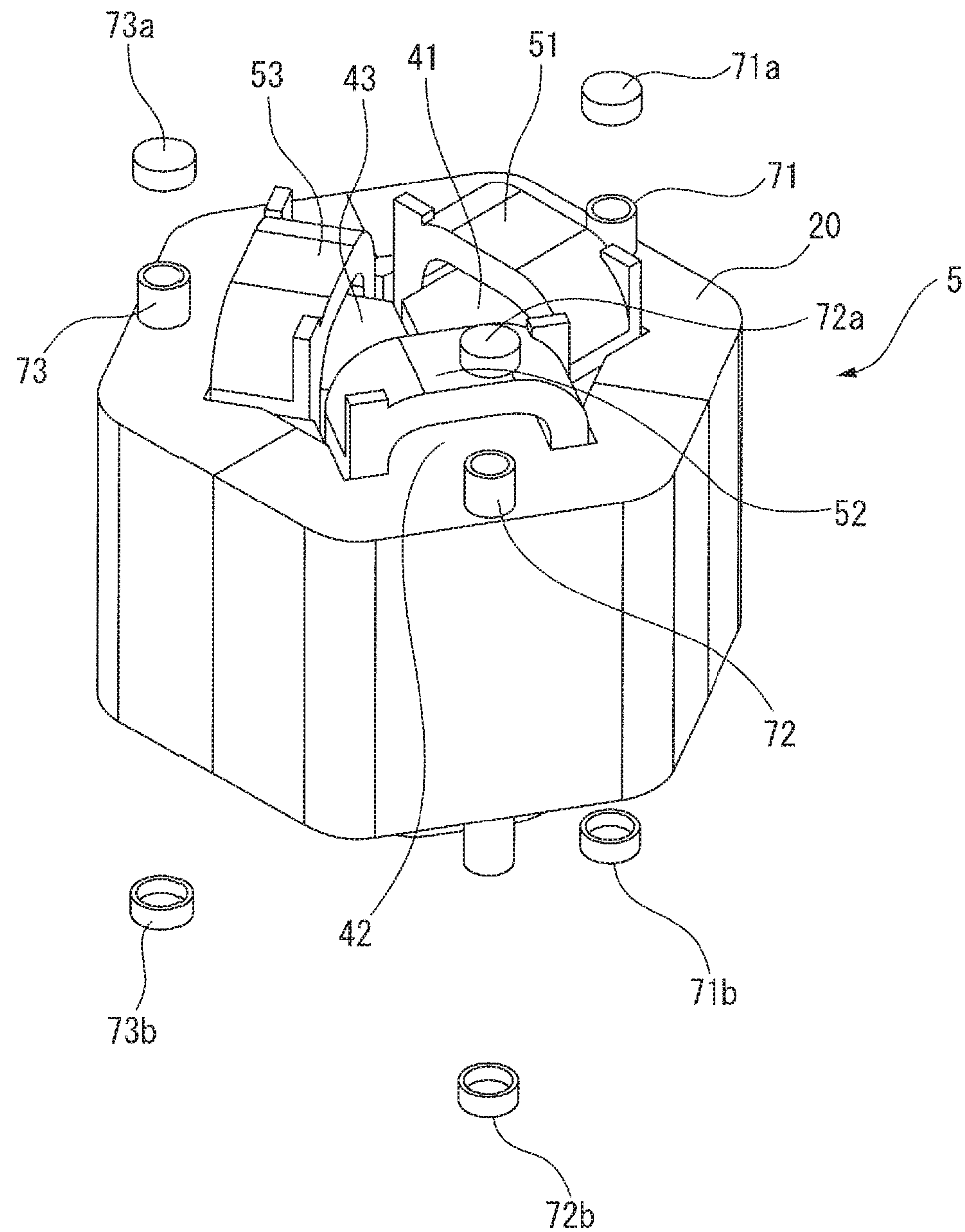


FIG. 10A

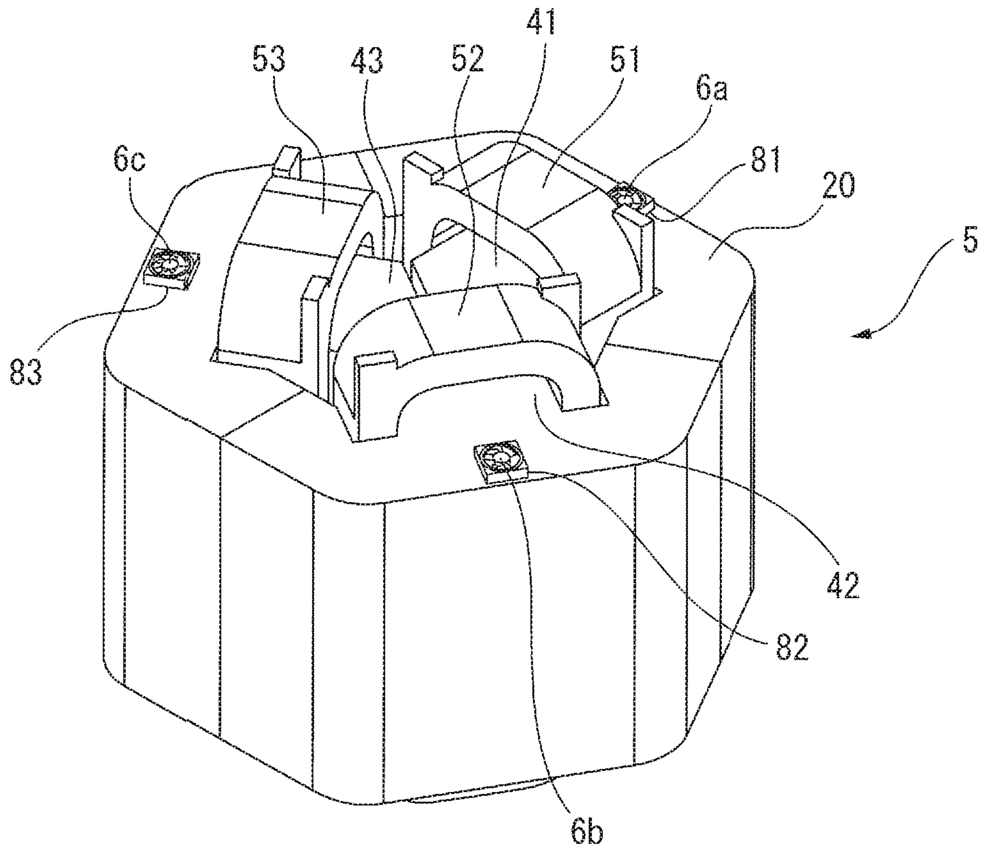


FIG. 10B

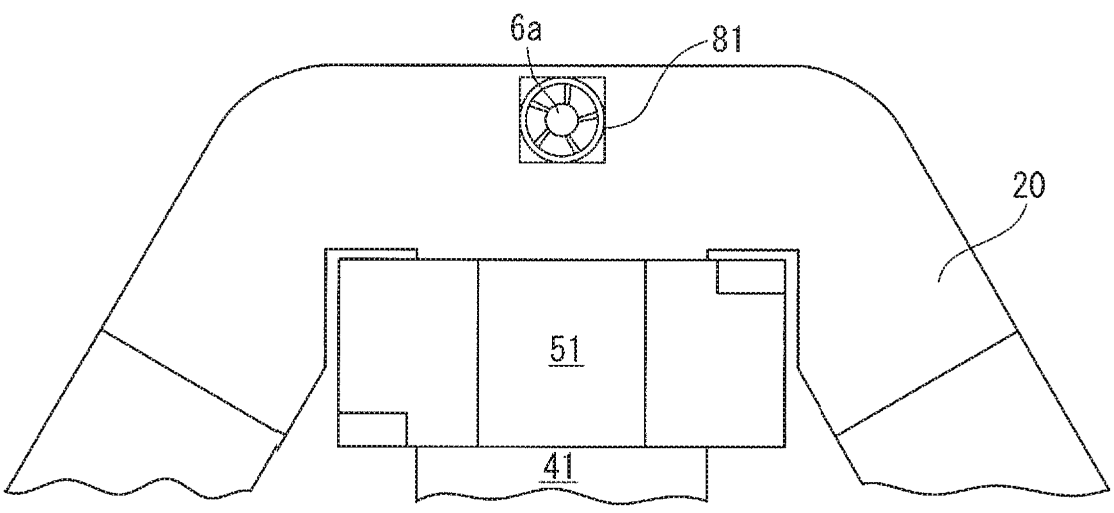


FIG. 11A

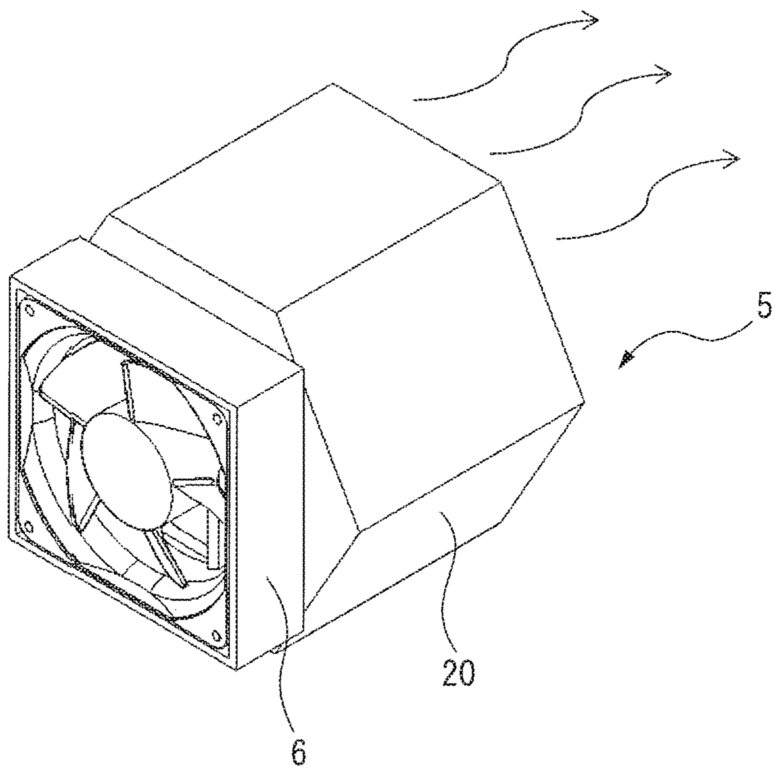


FIG. 11B

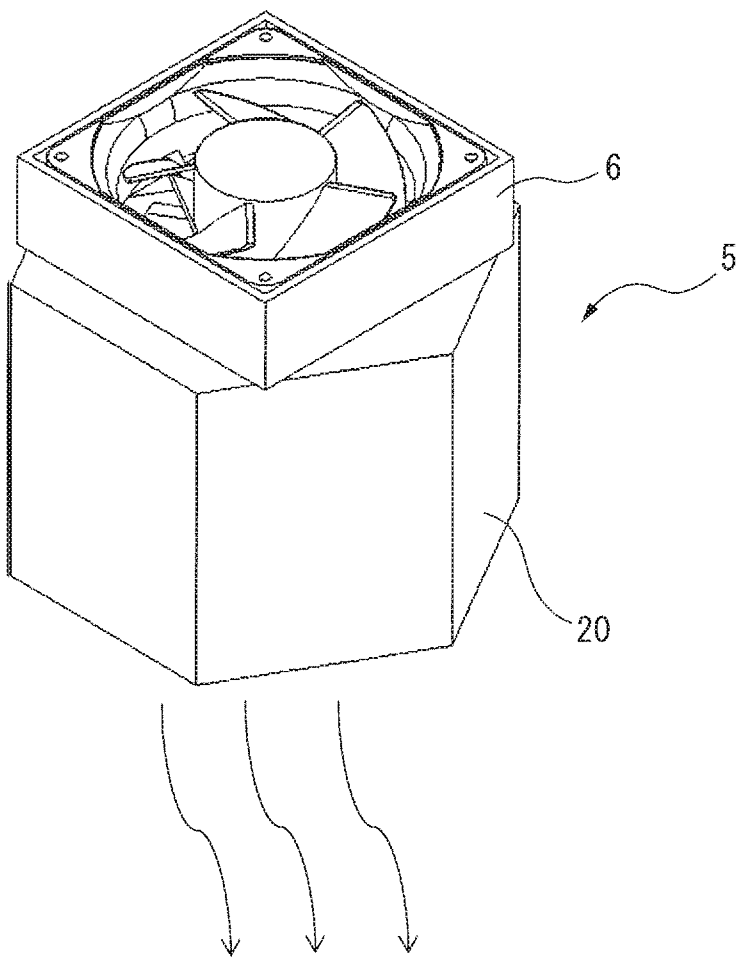


FIG. 12

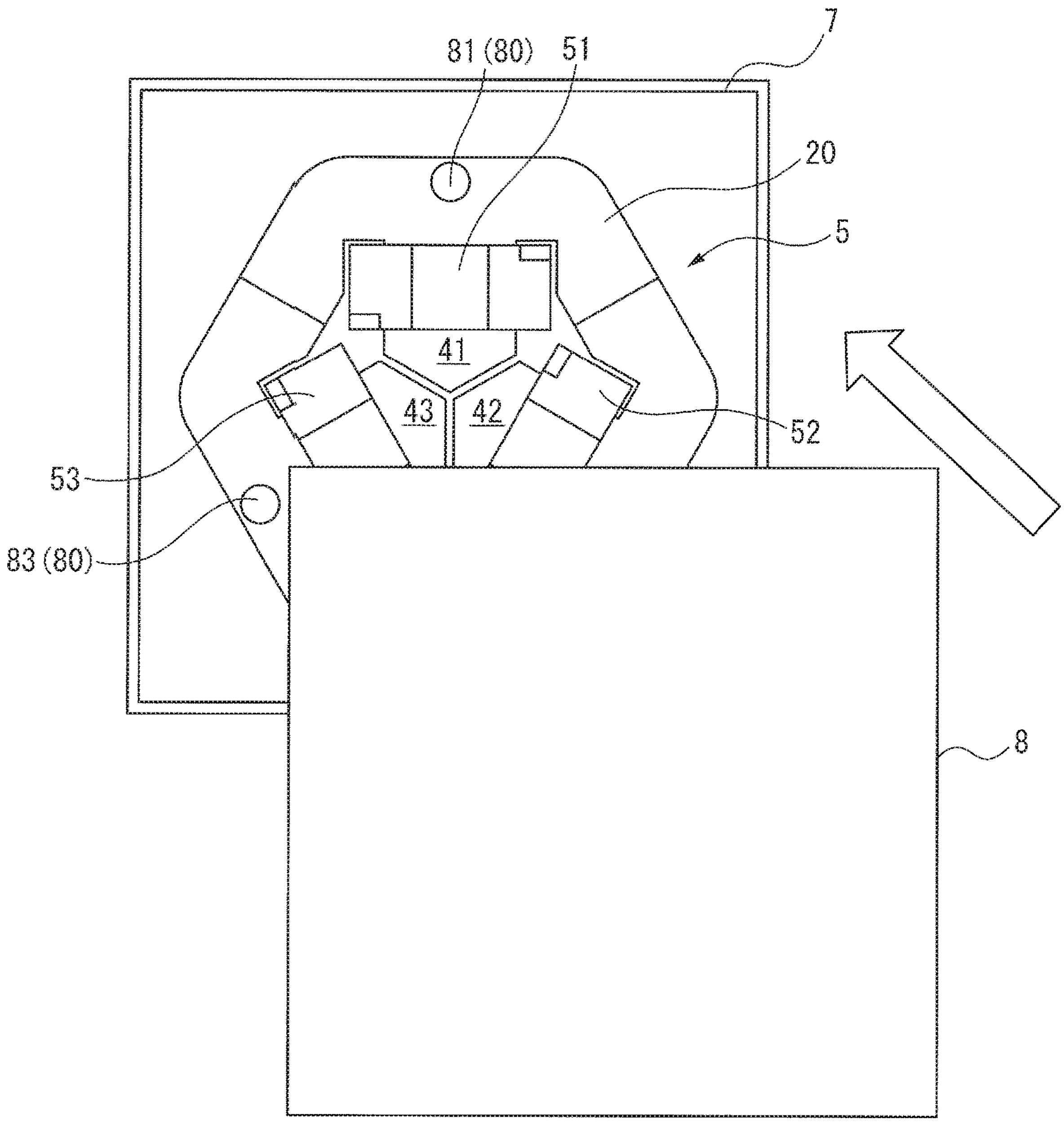
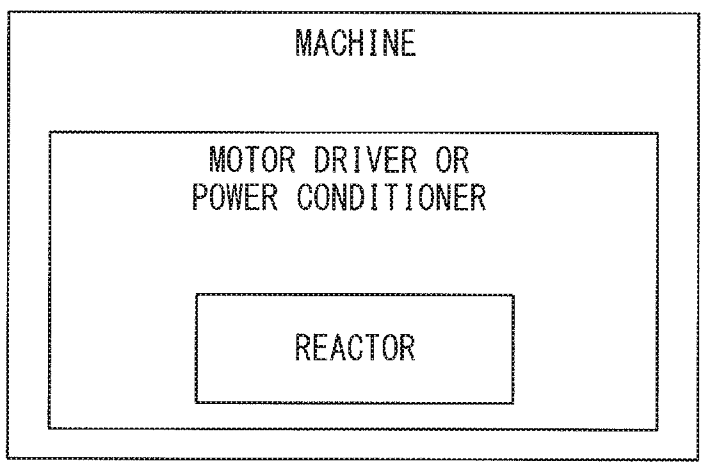


FIG. 13



REACTOR, MOTOR DRIVER, POWER CONDITIONER AND MACHINE

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a reactor, a motor driver, a power conditioner and a machine.

2. Description of Related Art

[0002] In general, reactors each have a plurality of cores and a plurality of coils wound onto the cores. In such reactors, when the coils magnetize the cores, an iron loss occurs which causes an increase in temperature.

[0003] Thus, Japanese Unexamined Patent Publication (Kokai) No. 2009-49082 discloses that "a reactor circulation path 64 is connected to the inside of a reactor case 32 of a reactor 30. The reactor case 32 contains cores 34 and coils 36, which constitute the reactor 30, and a coolant 66 circulates through space in the container."

SUMMARY OF THE INVENTION

[0004] However, since the reactor according to Japanese Unexamined Patent Publication (Kokai) No. 2009-49082 is disposed in the reactor case through which the coolant circulates, the structure is large.

[0005] Therefore, it is desired to provide a reactor that can be efficiently cooled with a simple structure without an increase in size, and a motor driver, a power conditioner and a machine having the reactor.

[0006] An embodiment of this disclosure provides a reactor that includes an outer peripheral iron core, and at least three core coils contacting or connected to an inner surface of the outer peripheral iron core. Each of the core coils includes a core and a coil wound onto the core. The reactor further includes a cooling unit which is disposed in an end surface of the outer peripheral iron core, for cooling the outer peripheral iron core.

[0007] According to the embodiment, since the cooling unit is disposed in the end surface of the outer peripheral iron core, the reactor can be efficiently cooled with a simple structure without an increase in size.

[0008] The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments along with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1**A is a top view of a reactor according to a first embodiment;

[0010] FIG. **1**B is a side view of the reactor shown in FIG. **1**A;

[0011] FIG. **2**A is a first view showing the magnetic flux density of the reactor according to the first embodiment;

[0012] FIG. **2**B is a second view showing the magnetic flux density of the reactor according to the first embodiment;

[0013] FIG. **2**C is a third view showing the magnetic flux density of the reactor according to the first embodiment;

[0014] FIG. **2**D is a fourth view showing the magnetic flux density of the reactor according to the first embodiment;

[0015] FIG. **2**E is a fifth view showing the magnetic flux density of the reactor according to the first embodiment;

[0016] FIG. **2**F is a sixth view showing the magnetic flux density of the reactor according to the first embodiment;

[0017] FIG. **3** is a graph showing the relationship between phase and current;

[0018] FIG. **4**A is a top view of an outer peripheral iron core according to the first embodiment;

[0019] FIG. **4**B is a top view of a reactor according to another embodiment;

[0020] FIG. **5** is a top view of an outer peripheral iron core of a reactor according to a second embodiment;

[0021] FIG. **6** is a top view of a reactor according to a third embodiment;

[0022] FIG. **7**A is a top view of a reactor according to a fourth embodiment;

[0023] FIG. **7**B is a drawing showing the magnetic flux density of the reactor according to the fourth embodiment;

[0024] FIG. **8** is a perspective view of a reactor according to a fifth embodiment;

[0025] FIG. **9** is a partly exploded perspective view of a reactor according to a sixth embodiment;

[0026] FIG. **10**A is a perspective view of a reactor according to a seventh embodiment;

[0027] FIG. **10**B is an enlarged view showing a part of the reactor shown in FIG. **10**A;

[0028] FIG. **11**A is a perspective view of a reactor according to an eighth embodiment;

[0029] FIG. **11**B is another perspective view of the reactor shown in FIG. **11**A;

[0030] FIG. **12** is a perspective view of a reactor according to a ninth embodiment; and

[0031] FIG. **13** is a block diagram of a machine including a reactor.

DETAILED DESCRIPTION OF THE INVENTION

[0032] Embodiments of the present invention will be described below with reference to the accompanying drawings. In the drawings, the same reference numerals indicate the same components. For ease of understanding, the drawings have been modified in scale in an appropriate manner.

[0033] FIG. **1**A is a top view of a reactor according to a first embodiment. As shown in FIG. **1**A, a reactor **5** includes an outer peripheral iron core **20** having a round cross-section and at least three core coils **31** to **33** contacting or connected to an inner surface of the outer peripheral iron core **20**. The number of cores is preferably an integral multiple of **3**, and the reactor **5** can be thereby used as a three-phase reactor. The outer peripheral iron core **20** may be polygonal in shape. The core coils **31** to **33** are in contact or integral with the inner surface of the outer peripheral iron core **20**.

[0034] The core coils **31** to **33** include cores **41** to **43** and coils **51** to **53** wound onto the cores **41** to **43**, respectively. Each of the outer peripheral iron core **20** and the cores **41** to **43** is made by stacking iron sheets, carbon steel sheets or electromagnetic steel sheets, or made of ferrite, an amorphous material or a pressed powder core.

[0035] As shown in FIG. **1**A, the cores **41** to **43** have approximately the same dimensions as each other, and are arranged at approximately equal intervals in the circumferential direction of the outer peripheral iron core **20**. In FIG. **1**A, the cores **41** to **43** contact or are connected to the outer peripheral iron core **20** at their radial outer end portions.

[0036] Furthermore, the cores **41** to **43** converge toward the center of the outer peripheral iron core **20** at their radial inner end portions each having an edge angle of approximately 120°. The radial inner end portions of the cores **41** to **43** are separated from each other by gaps **101** to **103**, which can be magnetically coupled.

[0037] In other words, in the first embodiment, the radial inner end portion of the core **41** is separated from the radial inner end portions of the two adjacent cores **42** and **43** by the gaps **101** and **103**, respectively. The same is true for the other cores **42** and **43**. The gaps **101** to **103** ideally have the same dimensions, but may have different dimensions. In embodiments described later, a description regarding the gaps **101** to **103**, the core coils **31** to **33**, and the like may be omitted.

[0038] As described above, in the first embodiment, the core coils **31** to **33** are disposed inside the outer peripheral iron core **20**. In other words, the core coils **31** to **33** are enclosed with the outer peripheral iron core **20**. The outer peripheral iron core **20** can reduce leakage of magnetic flux generated by the coils **51** to **53** to the outside.

[0039] Furthermore, in the first embodiment, at least one cooling unit, for example, three cooling units **80**, are disposed in the outer peripheral iron core **20**, as shown in FIG. **1**A. The cooling units **80** cool the inside of the outer peripheral iron core **20**, in particular the coils **51** to **53**. Since the cooling units **80** are laid out in the area of the outer peripheral iron core **20**, the reactor **5** can be efficiently cooled with a simple structure when the reactor **5** is driven.

[0040] FIG. **1**B is a side view of the reactor shown in FIG. **1**A. Each cooling unit **80** is constituted of a through hole (FIG. **1**B) formed so as to extend in an axial direction of the outer peripheral iron core **20**. When the reactor **5** is driven, heat dissipates through the through holes, thus cooling the reactor **5** with high efficiency.

[0041] As a non-illustrated embodiment, a single cooling unit **80** may be formed in the area of the outer peripheral iron core **20**. The cooling unit **80** need not necessarily have a circular cross-section, but may have an arcuate or rectangular cross-section extending in the circumferential direction of the outer peripheral iron core **20**.

[0042] FIGS. **2**A to **2**F are drawings showing the magnetic flux density of the reactor according to the first embodiment. FIG. **3** is a graph showing the relationship between phase and current. FIG. **4**A is a top view of the outer peripheral iron core according to the first embodiment. In FIG. **3**, the cores **41** to **43** of the reactor **5** are assigned to an R-phase, an S-phase and a T-phase, respectively. In FIG. **3**, the dotted line represents the R-phase current. The solid line represents the S-phase current. The dashed line represents the T-phase current.

[0043] When the electrical angle is $\pi/6$ in FIG. **3**, a magnetic flux density as shown in FIG. **2**A is obtained. In the same manner, when the electrical angle is $\pi/3$, a magnetic flux density as shown in FIG. **2**B is obtained. When the electrical angle is $\pi/2$, a magnetic flux density as shown in FIG. **2**C is obtained. When the electrical angle is $2\pi/3$, a magnetic flux density as shown in FIG. **2**D is obtained. When the electrical angle is $5\pi/6$, magnetic flux density as shown in FIG. **2**E is obtained. When the electrical angle is π, a magnetic flux density as shown in FIG. **2**F is obtained.

[0044] As is apparent from FIGS. **2**A to **2**F and FIG. **4**A, the magnetic flux density is lower in outer end portion correspondence positions **81** to **83**, which correspond to the radial outer end portions **41***a* to **43***a* of the cores **41** to **43**, respectively, of the outer peripheral iron core **20** than in the remaining portions of the outer peripheral iron core **20**. This is because less magnetic flux passes through the outer end portion correspondence positions **81** to **83**. In the same manner, the magnetic flux density is lower in intermediate positions **91** to **93** between the outer end portion correspondence positions **81** to **83** along the outer peripheral iron core **20** than in the remaining portions of the outer peripheral iron core **20**. Therefore, the cooling unit **80** is preferably disposed in at least one of the outer end portion correspondence positions **81** to **83** and the intermediate positions **91** to **93**. In this case, the reactor **5** can be cooled without having adverse effects on the magnetic characteristics of the reactor **5**. It is preferable that the width (radial distance) of the outer peripheral iron core **20**, which has the cooling units **80** in the outer end portion correspondence positions **81** to **83** and the intermediate positions **91** to **93**, be sufficiently wide. To be more specific, the remainder obtained by subtracting the radial distance of the cooling unit **80** disposed in each of the outer end portion correspondence positions **81** to **83** and the intermediate positions **91** to **93** from the width of the outer peripheral iron core **20** is preferably more than the radial distance of the cooling unit **80**. This reliably provides an area through which the magnetic flux can pass, even when the cooling units **80** are disposed in the outer end portion correspondence positions **81** to **83** and the intermediate positions **91** to **93**.

[0045] FIG. **4**B is a top view of a reactor according to another embodiment. In FIG. **4**B, a through hole constituting a cooling unit **80** is formed at approximately the center of a minimum width A**2** of an outer peripheral iron core **20** in each of outer end portion correspondence positions **81** to **83**. A**3** denotes the diameter of the through hole constituting the cooling unit **80** formed in the outer end portion correspondence position **81**. The remainder obtained by subtracting the diameter A**3** of the through hole constituting the cooling unit **80** from the minimum width A**2** of the outer peripheral iron core **20** (=A**2**−A**3**) is more than half of the width A**1** of a core **41**. In other words, even if the through hole is formed as the cooling unit **80**, the width of the outer peripheral iron core **20** is relatively wide. This allows the outer peripheral iron core **20** to have a cross-sectional area through which the magnetic flux can pass. Therefore, the cooling unit **80** has no effect on the magnetic characteristics of the reactor **5**. The same is true for the other outer end portion correspondence positions **82** and **83**.

[0046] FIG. **5** is a top view of an outer peripheral iron core of a reactor according to a second embodiment. In FIG. **5**, a reactor **5** includes an outer peripheral iron core **20** and six core coils **31** to **36** contacting or connected to an inner surface of the outer peripheral iron core **20**. The core coils **31** to **36** include cores **41** to **46** and coils **51** to **56** wound onto the cores **41** to **46**, respectively. As shown in the drawing, the core coils **31** to **36** are arranged at approximately equal intervals in the circumferential direction of the outer peripheral iron core **20**. The cores **41** to **43** are separated from each other at their radial inner end portions by gaps **101** to **106**, which can be magnetically coupled.

[0047] For the same reason as described above with reference to FIGS. **2**A to **2**F, a cooling unit **80** is preferably disposed in at least one of outer end portion correspondence positions **81** to **86** and intermediate positions **91** to **96** of the reactor **5**, as shown in FIG. **5**. In this case, it is apparent that the same effects as described above can be obtained.

[0048] Furthermore, FIG. **6** is a top view of a reactor according to a third embodiment. In FIG. **6**, a reactor **5**

includes an approximately octagonal outer peripheral iron core **20** and four core coils **31** to **34** contacting or connected to an inner surface of the outer peripheral iron core **20** in the same manner as described above. The core coils **31** to **34** are arranged at approximately equal intervals in the circumferential direction of the reactor **5**. The number of cores is preferably an even number more than **4**, and the reactor **5** can be thereby used as a single-phase reactor.

[0049] As is apparent from the drawing, the core coils **31** to **34** include cores **41** to **44** extending in the radial direction and coils **51** to **54** wound onto the cores **41** to **44**, respectively. The cores **41** to **44** are in contact or integral with the outer peripheral iron core **20** at their radial outer end portions.

[0050] Furthermore, radial inner end portions of the cores **41** to **44** are disposed in the vicinity of the center of the outer peripheral iron core **20**. In FIG. **6**, the cores **41** to **44** converge toward the center of the outer peripheral iron core **20** at their radial inner end portions each having an edge angle of approximately 90°. The radial inner end portions of the cores **41** to **44** are separated from each other by gaps **101** to **104**, which can be magnetically coupled.

[0051] For the same reason as described above with reference to FIGS. **2**A to **2**F, a cooling unit **80** is preferably disposed in at least one of outer end portion correspondence positions **81** to **84** and intermediate positions **91** to **94** of the reactor **5**, as shown in FIG. **6**. In this case, it is apparent that the same effects as described above can be obtained.

[0052] Furthermore, FIG. **7**A is a top view of a reactor according to a fourth embodiment. In FIG. **7**A, a reactor **5** includes a round outer peripheral iron core **20** and six core coils **31** to **36**. The core coils **31** to **36** include cores **41** to **46** and coils **51** to **56** wound on the cores **41** to **46**, respectively. The cores **41** to **46** are in contact or integral with an inner surface of the outer peripheral iron core **20**. A central core **10** is disposed at the center of the outer peripheral iron core **20**. The central core **10** is formed in the same manner as the outer peripheral iron core **20**. Each of gaps **101** to **106**, through which magnetic connection can be established, is formed between each of radial inner end portions of the cores **41** to **46** and the central core **10**.

[0053] FIG. **7**B is a drawing showing the magnetic flux density of the reactor according to the fourth embodiment. As is apparent from FIG. **7**B, the magnetic flux density is lower in the central position **89** of the central core **10** than in the outer peripheral iron core **20** and the cores **41** to **46**. Therefore, when the reactor **5** includes the central core **10**, a through hole is preferably disposed in the central position **89** of the central core **10** as a cooling unit **80**, in the same manner as described above. Therefore, the reactor **5** can be cooled without having adverse effects on the magnetic characteristics of the reactor **5** having the central core **10**.

[0054] A plurality of cooling units **80** may be provided in the central core **10**. The reactor **5** according to the fourth embodiment may have cooling units **80** in outer end portion correspondence positions and intermediate positions, in the same manner as described above.

[0055] Cooling units **80** of a reactor **5** having three core coils **31** to **33** will be described below in detail. FIG. **8** is a perspective view of a reactor according to a fifth embodiment. In FIG. **8**, each cooling unit **80** includes a through hole formed in each of outer end portion correspondence positions **81** to **83**. The cooling unit **80** further includes tubes **71** to **73** inserted into each through hole. The tubes **71** to **73** are preferably cooling pipes made of a material having a higher thermal conductivity than material of the outer peripheral iron core **20**.

[0056] In this case, heat dissipates through the tubes **71** to **73**, thus cooling the reactor **5** with high efficiency. Furthermore, coolant flowing from a non-illustrated coolant supply through the inside of the tubes **71** to **73** further enhances the cooling effect.

[0057] FIG. **9** is a partly exploded perspective view of a reactor according to a sixth embodiment. In FIG. **9**, lids **71*a*** to **73*a*** and **71*b*** to **73*b*** are fitted over both ends of tubes **71** to **73**. After the lids **71*b*** to **73*b*** are fitted over one ends of the tubes **71** to **73**, the tubes **71** to **73** are supplied with coolant. After that, the other lids **71*a*** to **73*a*** are fitted over the tubes **71** to **73** to close the tubes **71** to **73**, respectively. In this case, the reactor **5** can be cooled with higher efficiency. This eliminates the need for providing a coolant supply, thus preventing an increase in structure size.

[0058] FIG. **10**A is a perspective view of a reactor according to a seventh embodiment, and FIG. **10**B is an enlarged view showing a part of the reactor shown in FIG. **10**A. In the drawings, cooling fans **6*a*** to **6*c*** are attached to inlets of through holes formed in outer end portion correspondence positions **81** to **83**, respectively. The cooling fans **6*a*** to **6*c*** and a cooling fan **6** described later are driven by non-illustrated motors. The same cooling fans may be attached to the inlets of through holes and the like formed in intermediate positions **91** to **93**.

[0059] FIG. **11**A is a perspective view of a reactor according to an eighth embodiment, and FIG. **11**B is another perspective view of the reactor shown in FIG. **11**A. In FIG. **11**A, a reactor **5** is oriented such that an axial direction of the reactor **5** coincides with the horizontal direction. In FIG. **11**B, the reactor **5** is oriented such that the axial direction of the reactor **5** coincides with the vertical direction. In the drawings, a cooling fan **6** is attached to an end surface of an outer peripheral iron core **20**.

[0060] When the cooling fan **6** or the cooling fans **6*a*** to **6*c*** is driven, air flows from the cooling fan **6** or the cooling fans **6*a*** to **6*c*** through the through holes and gaps **101** to **103** in the axial direction of the reactor **5**. Thus, the reactor **5** has further increased cooling effect. Furthermore, the eighth embodiment requires only the single cooling fan **6**.

[0061] FIG. **12** is a perspective view of a reactor according to a ninth embodiment. In FIG. **12**, a reactor **5** is contained in a housing **7**. The housing **7** contains the reactor **5** having cooling units **80**. After or before the reactor **5** is disposed in the housing **7**, the housing **7** is filled with a predetermined amount of coolant. After the housing **7** is closed with a lid **8**, the reactor **5** is driven. Therefore, the coolant contained in the housing **7** contributes to cooling the reactor **5** more efficiently.

[0062] FIG. **13** is a block diagram of a machine including a reactor. In FIG. **13**, a reactor **5** is used in a motor driver or a power conditioner. The machine includes the motor driver or the power conditioner. In this case, the motor driver, power conditioner, machine and the like having the reactor **5** can be easily provided. The scope of the present invention includes appropriate combinations of some of the above-described embodiments.

Embodiments of Disclosure

[0063] A first embodiment provides a reactor (**5**) that includes an outer peripheral iron core (**20**), and at least three core coils (**31**-**36**) contacting or connected to an inner surface of the outer peripheral iron core. Each of the core coils includes a core (**41**-**46**) and a coil (**51**-**56**) wound onto the core. The reactor (**5**) further includes a cooling unit (**80**) disposed in an end surface of the outer peripheral iron core, for cooling the outer peripheral iron core.

[0064] According to a second embodiment, in the first embodiment, the cooling unit includes at least one through hole formed so as to extend in the axial direction of the outer peripheral iron core.

[0065] According to a third embodiment, in the second embodiment, the minimum width of the outer peripheral iron core excluding the through hole is more than half of the width of the core.

[0066] According to a fourth embodiment, the second or third embodiment further includes a cooling fan disposed inside the at least one through hole.

[0067] According to a fifth embodiment, in any one of the first to third embodiments, the cooling unit further includes a tube (**71**-**73**) inserted into the at least one through hole.

[0068] According to a sixth embodiment, in the fifth embodiment, an end of the tube is closed with a lid (**71***a*-**73***a*, **71***b*-**73***b*), and the tube is filled with coolant.

[0069] According to a seventh embodiment, the first or second embodiment further includes a housing for containing the outer peripheral iron core, the housing being filled with coolant.

[0070] According to an eighth embodiment, any one of the first to seventh embodiments further includes a central core (**10**) disposed at the center of the outer peripheral iron core. The cooling unit includes at least one through hole formed in the central core so as to extend in the axial direction.

[0071] A ninth embodiment provides a motor driver including the reactor according to any one of the first to eighth embodiments.

[0072] A tenth embodiment provides a machine including the motor driver according to the ninth embodiment.

[0073] An eleventh embodiment provides a power conditioner including the reactor according to any one of the first to eighth embodiments.

[0074] A twelfth embodiment provides a machine including the power conditioner according to the eleventh embodiment.

Advantageous Effects of the Embodiments

[0075] According to the first embodiment, since the cooling unit is disposed in the outer peripheral iron core, the reactor can be efficiently cooled with a simple structure.

[0076] According to the second embodiment, since heat dissipates through the through hole, the reactor can be cooled with high efficiency.

[0077] According to the third embodiment, even when the through hole is formed in the outer peripheral iron core, the outer peripheral iron core reliably has an area through which the magnetic flux can pass. Therefore, the cooling unit has no effect on the magnetic characteristics of the reactor.

[0078] According to the fourth embodiment, air flowing from the cooling fan through the through hole further enhances the cooling effect.

[0079] According to the fifth embodiment, heat can dissipate through the tube. Furthermore, coolant can flow through the tube.

[0080] According to the sixth embodiment, the coolant cools the reactor with higher efficiency.

[0081] According to the seventh embodiment, the coolant contained in the housing cools the reactor more efficiently.

[0082] According to the eighth embodiment, since heat dissipates through the through hole formed in the central core, the reactor can be cooled efficiently.

[0083] According to the ninth to twelfth embodiments, the motor driver, power conditioner and machine having the reactor can be easily provided.

[0084] The present invention is described above with reference to the preferred embodiments, but it is apparent for those skilled in the art that the above-described and other various modifications, omissions and additions can be performed without departing from the scope of the present invention.

What is claimed is:

1. A reactor, comprising:

an outer peripheral iron core;

at least three iron core coils contacting or connected to an inner surface of the outer peripheral iron core, wherein

each of the at least three iron core coils includes an iron core and a coil wound around the iron core,

the reactor further comprises:

a cooling unit arranged on an end surface of the outer peripheral iron core, for cooling the outer peripheral iron core, and

the cooling unit comprises at least one through-hole formed so as to extend in the axial direction of the outer peripheral iron core.

2. The reactor according to claim **1**, further comprising a housing for enclosing the outer peripheral iron core, the housing being filled with coolant.

3. The reactor according to claim **1**, wherein the minimum width of the outer peripheral core excluding the through-hole is greater than half of the width of the iron core.

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